

**SEAT BELT TENSION PREDICTION SYSTEM USING AN
ACCELEROMETER MOUNTED TO THE SEAT FRAME AND A WEIGHT
SENSOR**

CROSS REFERENCE TO RELATED APPLICATIONS

The instant application claims the benefit of copending U.S.

5 Provisional Application Serial No. 60/046,233, filed May 12, 1997.

Co-pending U.S. Application Serial No. 08/993,701[✓] entitled "Seat Weight Sensor Having Fluid Filled Bladder", filed on December 18, 1997, claiming benefit of U.S. Provisional Application Serial No.

60/032,380 filed on December 19, 1996, and assigned to the assignee
10 of the instant invention discloses a hydrostatic weight sensor comprising a fluid filled bladder and a pressure sensor for sensing the weight of an occupant in a vehicle seat for controlling a safety restraint system. U.S. Application Serial No. 08/993,701 also discloses a load distributor for distributing loads across the load bearing surface of the
15 hydrostatic weight sensor. U.S. Application Serial No. 08/993,701 and U.S. Provisional Application Serial No. 60/032,380 are incorporated herein by reference.

Co-pending U.S. Application Serial No. 09/003,672[✓] entitled
"Automotive Seat Weight Sensing System", filed on January 7, 1997,
20 claiming benefit of U.S. Provisional Application Serial No. 60/034,018 filed on January 8, 1997, and assigned to the assignee of the instant invention discloses a seat weight sensing system comprising a plurality of hydrostatic weight sensors each of which is in accordance with U.S. Application Serial No. 08/993,701. U.S. Application Serial No.
25 09/003,672 and U.S. Provisional Application Serial No. 60/034,018 are incorporated herein by reference.

Co-pending U.S. Application Serial No. 09/003,870[✓] entitled
"Vehicle Seat Sensor Having Self-Maintaining Air Bladder", filed on January 7, 1997, claiming benefit of U.S. Provisional Application Serial

30 No. 60/035,343 filed on January 16, 1997, and assigned to the
assignee of the instant invention discloses an apparatus for
automatically maintaining the supply of sensing fluid in a hydrostatic
weight sensor. U.S. Application Serial No. 09/003,870 and U.S.
Provisional Application Serial No. 60/035,343 are incorporated herein by
35 reference.

Co-pending U.S. Application Serial No. 09/003,868[✓] entitled "Seat
Weight Sensor with Means for Distributing Loads", filed on January 7,
1997, claiming benefit of U.S. Provisional Application Serial No.
60/058,084 filed on September 4, 1997, and assigned to the assignee
40 of the instant invention discloses a load distributor for distributing
sensed load across the load bearing surface of a hydrostatic weight
sensor. U.S. Application Serial No. 09/003,868 and U.S. Provisional
Application Serial No. 60/058,084 are incorporated herein by reference.

Co-pending U.S. Application Serial No. 09/003,673[✓] entitled "Seat
45 Weight Sensor Having Self-Regulating Fluid Filled Bladder", filed on
January 7, 1997, claiming benefit of U.S. Provisional Application Serial
No. 60/058,119 filed on September 4, 1997, and assigned to the
assignee of the instant invention discloses a hydrostatic weight sensor
having a means for automatically regulating the amount of sensing fluid
50 therein. U.S. Application Serial No. 09/003,673 and U.S. Provisional
Application Serial No. 60/058,119 are incorporated herein by reference.

Co-pending U.S. Application Serial No. 09/003,746[✓] entitled "Seat
Weight Sensor Using Fluid Filled Tubing", filed on January 7, 1997,
claiming benefit of U.S. Provisional Application Serial No. 60/065,986
55 filed on November 14, 1997, and assigned to the assignee of the instant
invention discloses a hydrostatic weight sensor incorporating a fluid
filled tube. U.S. Application Serial No. 09/003,746 and U.S. Provisional
Application Serial No. 60/065,986 are incorporated herein by reference.

Co-pending U.S. Application Serial No. 09/003,744[✓] entitled "Low
60 Profile Hydraulic Seat Weight Sensor", filed on January 7, 1997,
claiming benefit of U.S. Provisional Application Serial No. 60/065,832

filed on November 14, 1997, and assigned to the assignee of the instant invention discloses a hydrostatic weight sensor constructed from plates or sheets of semi-rigid material and filled with a liquid, grease, Bingham
65 fluid or thixotropic material. U.S. Application Serial No. 09/003,744 and U.S. Provisional Application Serial No. 60/065,832 are incorporated herein by reference.

TECHNICAL ART

The instant invention relates generally to automotive passenger
5 restraint systems and more specifically to a system and method for predicting seatbelt tension in a vehicle utilizing a seat weight sensor and an accelerometer.

BACKGROUND OF THE INVENTION

Automotive manufacturers and the National Highway
5 Transportation Safety Association are investigating methods to disable vehicle air bags in situations where they may cause more harm than good. Typically, airbags have been developed to deploy with enough force to restrain a 175 lb. adult in a high velocity crash. Deployment of the same air bags when children are seat occupants may cause serious
10 injury due to the force generated upon inflation of the bag.

As a result, seat weight sensors and systems are being developed in an attempt to determine when the passenger seat occupant is a child.

Such systems should identify when the occupant is small, or even
15 when a child is in a rear facing infant seat, a forward facing child seat or a booster seat. Occupant weight measurement when a child seat is present is further complicated by the downward force applied to the child seat by the tension of a seat belt. When a child seat is strapped tightly, the seat belt forces the child seat into the vehicle seat and can

- 20 often artificially increase the measured weight, which may lead to air bag deployment when children or infants are present in the seat.

A variety of methods have been used for seat belt tension measurement. Copending U.S. Provisional Application Serial No. 25 60/067,071 entitled "Villari Effect Seat Belt Tension Sensor", and copending U.S. Provisional Application Serial No. 60/070,319 entitled "Compressive Villari Effect Seatbelt Tension Sensor", both assigned to the assignee of the instant invention, disclose two seat belt tension measurement systems utilizing sensors that operate on the principle 30 known as the Villari effect. The Villari effect refers to the tendency of certain materials with magnetostrictive properties to inhibit or enhance the strength of an electromagnetic field within the material when the material is being subjected to compression or tensile stress. By measuring the field strength in magnetostrictive material placed in line 35 with a seat belt mechanism, for example in a seat belt latch or a seat belt retractor, the relative tension in the belt may be calculated.

Furthermore, belt deflection techniques which guide a seat belt through a mechanical system that forces the belt out of a straight line 40 when there is low tension have been used. Under high tension the seat belt forces the displacement of a mechanical deflector. This force may then be sensed utilizing an electromechanical switch. Tension measurement mechanisms have also been incorporated in the buckle of the seat belt. In one embodiment, a sliding buckle is biased back with a 45 spring. When the belt is under heavy tension, the buckle pulls forward to control a switch that provides feedback to a vehicle processor.

The aforementioned seat belt tension measurement methods suffer from a number of disadvantages. Initially, a great number of additional 50 parts are required for seat belt retractors or buckle configurations. This adds complexity (and therefore cost) to vehicle assembly and provides

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for considerable difficulty in retrofitting existing vehicles. Additionally, several of the aforementioned tension systems provide only a threshold level of tension detection.

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The present invention may be used to detect whether the seat belt is under high tension thereby denoting that an infant seat is present. Furthermore, significant tension in the belt can be predicted without resorting to the complex instrumentation required to measure actual belt
60 tension. Known belt tension measurement systems that directly contact the seat belt require additional hardware and sensors that increase component count and vehicle assembly complexity.

SUMMARY OF THE INVENTION

The instant invention overcomes the aforementioned problems by
5 providing a seat belt tension prediction system employing an accelerometer and a seat weight sensor to accurately determine the tension in a vehicle seat belt and thereby discriminate between the presence of a tightly belted child seat or other object and an adult occupant.

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The instant invention measures the "bounce", or vertical acceleration, experienced by a weight on a seat weight measurement means by monitoring an accelerometer that is rigidly mounted to the vehicle seat. The bounce can be thought of as the temporary
15 acceleration of the weight on the seat caused by the vehicle traversing bumps or holes in the road. This road-induced bounce causes oscillations in the force acting upon the seat that may be measured by a seat weight sensor.

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A "free" or unbelted mass positioned on a vehicle seat will bounce up and down on the seat and may, for example, completely lose contact

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with the seat in extreme cases. The weight sensor would correspondingly interpret this extreme case as a "spike" of zero force acting on the seat. Usually, however, the output signal produced by the weight sensor will oscillate with a small amplitude that is dependent upon the total mass acting upon the seat and the amplitude of the road-induced vehicle bounce. When the force acting downwardly on the seat is increased due to the tension in a tight seat belt, the amplitude of oscillation of an output signal produced by the weight sensor will be reduced because a component of the force caused by the tension in the seatbelt is constant. Accordingly, a seatbelt tension may be calculated by determining the vertical acceleration of the vehicle and the variation in force exerted on the seat as measured by the seat weight sensor.

A conventional accelerometer provides an electrical signal proportional to the vertical acceleration that the seat, and therefore the mass in the seat, experiences. When actual vertical acceleration is compared to the oscillating output signal produced by the weight sensor, a measure of the force on the seat attributable to the tension in the seat belt may be calculated. The road-induced vertical acceleration acting on the vehicle is used to predict the amount of force exerted downwardly on the seat given that no seat belt tension is present.

A conventional microprocessor is adapted to accept output signals from the accelerometer and the seat weight sensor. The accelerometer output is responsive to the amount of vertical acceleration caused by road bounce acting on the vehicle seat and the weight sensor output is responsive to the amount of force exerted downwardly on the vehicle seat.

A normalized measurement of seatbelt tension may be calculated by the processor by first calculating an average mass on the seat using the weight sensor output. The expected variation in force is then

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calculated by multiplying the aforementioned average mass on the seat
55 by the actual acceleration as measured by the accelerometer over a
predetermined time period. A normalized seatbelt tension may then be
calculated by dividing the variation in force as measured by the seat
weight sensor over a predetermined time period by the expected or
calculated variation in force over the aforementioned period.

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The resultant scalar tension measure will approximate unity for
unbelted or loosely belted occupant situations where the mass acting on
the seat is free to travel vertically. Accordingly, the normalized tension
scalar will decrease when extremely high belt tension is present thereby
65 forcing the mass onto the seat.

Alternatively, the processor may calculate an expected force
exerted on the seat due to road-induced vehicle bounce at discrete time
intervals, assuming that no belt tension exists, and compare the results
70 with the measured force exerted on the seat at the each discrete point
in time. The ratio between the measured force and the calculated or
expected force exerted on the seat provides an indication of belt
tension.

75 Known seat weight sensors may comprise one or more pads
employing force sensitive resistive (FSR) elements disposed within the
seat to provide a weight measurement. These arrangements are
typically used as weight threshold systems that are used in conjunction
with a processor to disable a passenger air bag when the seat is empty.

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Conventional load cells attached to the seat mounting posts have
also been used in research applications. The use of load cells as weight
measurement means in the instant invention requires that the seatbelts
or passenger restraints are not mounted directly to the vehicle seat
85 because a load cell system that weighs the entire seat and its contents

including the seatbelts and their mounting points will not be responsive to the force applied to the seat by the tension in the seatbelt.

Mechanisms employing string actuated potentiometers to measure
90 downward seat displacement have also been utilized as weight
measurement means. In these mechanisms, a weight resting upon a
seat pad causes the pad to sag or curve downwardly, thereby displacing
a string that is positioned across the bottom of the seat pad. One end
of the string is connected to a potentiometer shaft that is rotated when
95 the string is displaced. The rotation of the potentiometer shaft causes
the resistance at the potentiometer output to change. A processor is
adapted to measure the changing resistance at the potentiometer
output, thereby providing a signal proportional to string displacement,
and therefore, the force caused by a mass present on the seat.

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Coping U.S. Application Serial No. 08/993,701 further
discloses a weight sensor employing a gas filled bladder disposed within
the seat pad to calculate seat weight. When a load is applied to the
seat a differential pressure sensor operatively coupled to the bladder
105 generates a signal that is responsive to the pressure on the fluid within
the bladder and therefore indicative of the force acting upon the seat. A
signal processor having an input operatively coupled to the pressure
sensor then calculates the force exerted on the seat as well as the mass
present.

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By determining the amount of mass present in a vehicle seat and
the amount of tension present in a passenger restraint belt, corrective
action may be taken to further protect a vehicle occupant by adapting
other restraint system components, such as the air bag control system.

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The ability to sense the tension present in a seat belt may be used
in conjunction with a seat weight sensor to determine the presence of

an occupant in a vehicle seat and the relative size of the occupant. This information may be used either to deactivate seatbelt pretensioners, and/or modify the inflation profile of an air bag.

Furthermore, by sensing the amount of tension present in the seat belt, the deployment of an airbag may be inhibited in the presence of infant seats or in situations where occupants are small so as to reduce their risk of injury from the inflating air bag. Therefore, a system that can reliably predict the amount of tension present in a seat belt may be used to great advantage in vehicle safety systems.

One significant advantage of the instant invention is that it does not require numerous ancillary components that are in direct contact with the seat belt system. The present invention can predict whether there is significant tension in the seat belt without directly measuring seat belt tension.

Therefore, one object of the instant invention is to provide a seat belt tension measurement system that does not require a mechanism in direct contact with the seat belt or its associated assembly.

Another object of the instant invention is to use road-induced vertical acceleration exerted on every vehicle as a forcing function for a seat weight sensor signal. The oscillation of an accelerometer signal compared with the oscillation of a weight sensor signal at discrete time intervals provides the data required to calculate seat belt tension.

A yet further object of the present invention is to provide a seat belt tension prediction system that requires minimal additional components beyond a seat weight measurement means and the attendant processor adapted to receive and process various vehicle instrumentation signals. The instant invention requires only an

150 accelerometer or equivalent acceleration sensing device and a
conventional microprocessor or equivalent processing means in
conjunction with a seat weight sensor to accurately calculate seat belt
tension.

155 A yet further object of the instant invention is to provide a seat
belt tension prediction system that is useful in determining the presence
of an infant seat in a vehicle. The present invention measures the
component of force acting on a vehicle seat that is attributable to
tension in the seat belt as well as the component of force attributable to
160 the presence of a mass on the seat, thereby providing a means to
predict whether the occupant is an adult or a child.

The instant invention will be more fully understood after reading
the following detailed description of the preferred embodiment with
165 reference to the accompanying drawings. While this description will
illustrate the application of the instant invention in an automotive safety
restraint system, it will be readily understood by one of ordinary skill in
the art that the instant invention may also be utilized in other tension
measurement systems.

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BRIEF DESCRIPTION OF THE DRAWINGS

✓ Fig. 1 is a diagrammatical view of a preferred embodiment of the instant
invention.

5 ✓ Fig. 2 is a diagrammatical view of an alternative seat weight sensor arrangement
taken along the line 2-2 of Fig. 1.

✓ Fig. 3 is a diagrammatical view of an alternative embodiment of the instant
invention.

✓ Fig. 4 is a diagrammatical view of an alternative embodiment of the instant
10 invention.

✓ Fig. 5 is a view of the instant invention taken along the line 5-5 of Fig. 4.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

Referring to Fig. 1, a seat belt tension prediction system and method 10 for a vehicle 12 having a seat 14 is comprised of an accelerometer 20 and a seat weight sensor 30. The accelerometer 20 is provided with an output signal 22 that is responsive to the amount of vertical acceleration acting upon the vehicle 12 and, therefore, on the vehicle seat 14. The accelerometer 20 must be rigidly secured to a vehicle structural member 16 that experiences the same vertical acceleration that the vehicle seat 14 is subjected to when traversing variations in terrain. In a preferred embodiment of the instant invention the resolution of the accelerometer 20 is greater than .005 g to provide sufficient sensitivity to small variations in vertical acceleration.

The seat weight sensor 30 is provided with an output signal 32 that is responsive to the amount of force exerted downwardly on the vehicle seat 14. Accordingly, the seat weight sensor output signal 32 will also be responsive to additional force upon the vehicle seat 14 exerted by tension in a seat belt 34. The output signal 32 from the weight sensor 30 must have an update period small enough to allow the weight sensor 30 to sense oscillations in force on the seat 14 caused by the vehicle's vertical acceleration. In a preferred embodiment of the instant invention the update period of the weight sensor output signal 32 is less than 25 milliseconds. Additionally, the weight sensor output signal 32 may be AC coupled to filter low frequency signal oscillations that normally occur as a result of occupant movement, thus ignoring those oscillations that are not produced by road-induced vertical acceleration.

Furthermore, a processor 50 is provided, having a first input 52 operatively coupled to the accelerometer output signal 22 and a second

input 54 operatively coupled to the seat weight sensor output signal 32.

The processor 50 is further operatively coupled to a vehicle airbag control system 60 whereby the processor 50 may provide an output
35 signal 56, or a plurality thereof, to the airbag control system 60 to inhibit deployment of an airbag and/or to modify its inflation profile.

The processor 50 may comprise an analog or digital microprocessor or any equivalent thereof. Although the preferred
40 embodiment of the instant invention utilizes a conventional digital microprocessor, it is readily understood by one having ordinary skill in the art that alternative means such as relay logic circuitry, analog processors, analog to digital converters and TTL logic circuitry may be employed as processor means to practice the instant invention.

In an alternative embodiment of the instant invention shown in FIG. 2, seat weight sensor 40 comprises a plurality of force sensitive
45 resistive elements 42 disposed within the vehicle seat 14 for measuring force. The force sensitive resistive elements 42 provide as an output
50 signal 44 a variable electrical resistance responsive to the amount of force acting on the elements 42, that may be operatively coupled to the input 54 of processor 50. The variable resistance output signal 44 is generally inversely proportional to the amount of force acting on the seat 14.

Referring to Fig. 3 and as disclosed in U.S. Application Serial No. 08/993,701, a hydrostatic seat weight sensor 70 as incorporated in an
55 alternative embodiment of the instant invention, comprises a gas filled bladder 72 mounted within the vehicle seat 14 and a differential
60 pressure sensor 74 operatively coupled to the bladder 72 for measuring the difference in pressure between the bladder 72 and the atmosphere. The differential pressure sensor 74 provides a pressure sensor output 76 that is responsive to the force exerted downwardly on the seat 14. The

65 differential pressure sensor output 76 is operatively coupled to input 54
of processor 50 thereby providing an indication of the force acting
downwardly on the seat 14.

70 As shown in FIG. 4, an alternative seat weight sensor comprises a
plurality of load cells 80 disposed between the vehicle seat 14 and the
vehicle structure 16 such that the entire weight of the seat 14 rests
upon the load cells 80. The load cells 80 are provided with an output
82 that is responsive to the amount of force acting upon the seat 14.
When utilizing load cells 80 as a weight sensors, it is critical that the
seat belt 34 is mounted to the vehicle 12 such that load cell 80 is
75 responsive to the force upon the seat 14 generated by tension present
in the seat belt 34. For example, Figs. 4 and 5 provide illustrations of a
seat belt 34 configuration wherein the load cells 80 are responsive to
both the tension applied by the seat belt 34 and the force resulting from
a mass resting on the seat 14.

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In operation, and in accordance with the preferred embodiment of
the instant invention, the accelerometer 20 measures the vertical
acceleration of the seat 14 and provides an output signal 22 to the
processor 50. A normalized seatbelt tension measure is then calculated
85 by the processor 50 to detect high belt tension and thereby determine
the presence of a child seat.

The processor 50 is programmed to calculate an average mass of
an object resting on the seat by dividing the output 32 of the weight
90 sensor 30 by the earth's gravitational constant, g. This calculation may
be performed at a predetermined time during the operation of the vehicle
12, or preferentially, performed continuously by assuming that the
vertical acceleration of the vehicle 12 and the belt tension are negligible,
and averaging the resultant successive mass calculations.

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A predicted variation in force exerted on the **seat 14** is calculated in the **processor 50** by multiplying the aforementioned average mass by the measured variation in vertical acceleration as provided by the **accelerometer 20** over a predetermined time period. The variation in vertical acceleration over time may be determined by integrating the absolute value of the difference between the **accelerometer output 22** and the earth's gravitational constant g over the aforementioned time period.

The variation, or fluctuation of the actual force exerted on the **seat 14** is then determined by integrating the absolute value of the difference between the seat weight sensor **output 32** and the average force exerted on the **seat 14**. The normalized tension measurement is then calculated by dividing the variation in actual force exerted on the seat over the same time period as measured by the **weight sensor 30**, by the predicted variation in force exerted on the **seat 14**. The time period over which the predicted force variation is calculated must be sufficient to allow road induced bounce to impart vertical acceleration to the **vehicle 12**. In a preferred embodiment of the instant invention the time period used to calculate the normalized belt tension is .5 seconds.

In an alternative embodiment of the instant invention the **processor 50** calculates the force exerted downwardly on the **seat 14** at discrete time intervals utilizing the vertical acceleration measurement provided by the **accelerometer 20**, and assuming that no **seat belt 34** tension is present in the system, and then compares the resultant predicted force with the actual measured force at each discrete point in time to calculate belt tension. As an example, the predicted force acting on the **seat 14** may be calculated by programming the **processor 50** to perform the following algorithm:

$$F = M(g-A) + BT, \text{ where}$$

F is the force acting downwardly onto the seat **14**,

M is the mass of the object on the seat **14**,

130 **g** is the gravitational acceleration exerted on the mass **M** by the earth,

A is the vertical acceleration of the vehicle **12**, excluding the earth's gravity, and

BT is the vertical component of the tension present in the belt **34**.

135 The vertical acceleration **A** of the vehicle **12** fluctuates around zero and thus causes variations in the force **F** acting on the seat **14**.

The belt tension **BT** approximates a constant value that is near zero for most occupant seating situations except for the presence of tightly belted child seats. The belt tension **BT** is generally a small value

140 because belt tension greater than a few pounds of force has been found to be uncomfortable for most vehicle occupants thereby making it unlikely that an occupant is present when there is significant tension in the seat belt **34**.

145 As previously disclosed, the output signal **32** of the weight sensor **30** is divided by the earth's gravitational constant **g** by processor **50** to calculate the average mass **M** present in the vehicle seat **14**. The processor **50** then calculates a predicted force acting downwardly on the seat **14** at discrete time intervals using the aforementioned average mass, with the assumption that the belt tension **BT** is zero. Still assuming zero belt tension **BT**, the processor **50** then compares the
150 actual value of the force **F** as measured at each discrete point in time by the weight sensor **30** with the calculated or predicted force. The difference between the predicted and actual values of force **F** provides
155 an indication of the tension present in the belt **BT**.

In an alternative method for predicting belt tension **BT**, the processor **50** monitors the weight sensor output signal **32** at discrete time intervals and measures the amplitude of the oscillations of the

160 **output signal 32** at each discrete point in time. The **processor 50**
further monitors the **accelerometer output signal 22** at the
corresponding discrete time intervals and calculates the amplitudes of
the oscillations of the **accelerometer output signal 22**. The resultant
accelerometer amplitude measurements are then sequentially multiplied
165 by the average mass **M** present in the **vehicle seat 14** to calculate the
predicted force acting on the **seat 14** at each discrete point in time.
The ratio of the actual force acting on the **seat 14** to the calculated
force at each time interval thereby provides a measure of seat belt
tension.

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A tightly belted mass present in the **vehicle seat 14** will produce a
reduced ratio of actual force to predicted force as compared to the ratio
calculated when a "free" mass is positioned in the **vehicle seat 14**.
Therefore, the smaller the ratio between actual force as indicated by the
175 **weight sensor 30** to predicted force as calculated using the average
mass **M** and the **accelerometer output signal 22**, the greater the belt
tension **BT**, and the higher the probability that an infant seat is tightly
belted down onto the **vehicle seat 14**. The **processor 50** may be
provided with a look-up table whereby **seat belt 34** tension may be
180 determined given a specific calculated tension ratio.

Accordingly, and as shown in Fig. 1, where the **processor 50**
calculates a level of tension in the **seat belt 34** in excess of a
predetermined maximum, the **processor 50** will generate an **output 56**
185 operatively coupled to an **air bag control system 60** to inhibit
deployment of the air bag. Alternatively, where the **processor 50**
calculates a level of tension in the **seat belt 34** below the predetermined
maximum and the **seat weight sensor 30** indicates that the occupant's
weight is below a predetermined minimum, the **processor 50** will provide
190 an **output 56** to the **air bag control system 60** to reduce the inflation
profile thereof according to the measured weight of the occupant.

While specific embodiments of the instant invention have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

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